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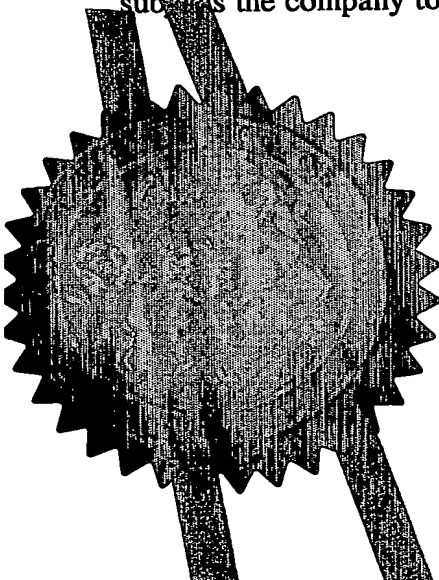
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2.	Patent application number (The Patent Office will fill in this part)	0217815.0 01AUG02 E737711-1 D00225 01 AUG 2002 P01/7700 0.00-0217815.0
3.	Full name, address and postcode of the or of each applicant (underline all surnames)	MICROSAIC SYSTEMS LIMITED 8 Clifford Street London W1S 2LQ England
	Patents ADP number (if you know it)	8225435002
	If the applicant is a corporate body, give the country/state of its incorporation.	United Kingdom
4.	Title of Invention	MONOLITHIC MICRO-ENGINEERED MASS SPECTROMETER
5.	Name your agent (if you have one)	TOMKINS & CO P. O. BOX NO. 668 ASCOT, BERKS, SL5 8YT
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Title

Monolithic Micro-engineered Mass Spectrometer

Field of the Invention

5 The invention relates to mass spectrometers and in particular to micro-engineered mass spectrometers.

Background to the Invention

10 Mass spectrometers are well known in the art and have particular application in sample measurements. It is also well known to provide miniaturised devices which have particular application as portable measurement systems. The use of such spectrometers is varied from the detection of  
15 biological and chemical materials, drugs, explosives and pollutants, as instruments for space exploration, to use as residual gas analysers. Mass spectrometers consist of three main subsystems: an ion source, an ion filter, and an ion counter. Since these may all be based on different  
20 principles, there is scope for a variety of systems to be constructed.

One of the most successful variants is the quadrupole mass spectrometer, which uses a quadrupole electrostatic lens as a  
25 mass filter. Conventional quadrupole lenses such as those described in Batey J.H. "Quadrupole gas analysers" Vacuum 37, 659-668 (1987), consist of four cylindrical electrodes, which are mounted accurately parallel and with their centre-to-centre spacing at a well-defined ratio to their diameter.

30 Ions are injected into a pupil located between the electrodes, and travel parallel to the electrodes under the influence of a time-varying hyperbolic electrostatic field. This field contains both a direct current (DC) and an  
35 alternating current (AC) component. The frequency of the AC

component is fixed, and the ratio of the DC voltage to the AC voltage is also fixed. Studies of the dynamics of an ion in such a field have shown that only ions of a particular charge to mass ratio will transit the quadrupole without  
5 discharging against one of the rods. Consequently, the device acts as a mass filter. The ions that successfully  
~~exit the filter may be detected.~~ If the DC and AC voltages are ramped together, the detected signal is a spectrum of the different masses that are present in the ion flux. The  
10 largest mass that can be detected is determined by the largest voltage that can be applied.

The resolution of a quadrupole filter is determined by two main factors: the number of cycles of alternating voltage  
15 experienced by each ion, and the accuracy with which the desired field is created. So that each ion experiences a large enough number of cycles, the ions are injected with a small axial velocity, and a radio frequency (RF) AC component is used. This frequency must clearly be increased  
20 as the length of the filter is reduced. In order to create the desired hyperbolic field, highly accurate methods of construction are employed. However, it becomes increasingly difficult to obtain the required precision as the size of the structure is reduced.

25 The sensitivity and hence the overall performance of a mass spectrometer is also affected by the ion flux, which is also clearly reduced as the size of the entrance pupil is decreased.

30 Several miniaturised quadrupole mass spectrometers have been constructed. Two examples of such instruments are based on square arrays of miniaturised electrostatic quadrupole lenses and are described in US 5,401,962 and  
35 US 5,719,393. The advantage of using an array is that

parallel operation can recover the sensitivity lost by miniaturisation. The square array geometry is particularly efficient, because an array of  $N^2$  quadrupoles only requires  $(N+1)^2$  electrodes.

5

The device disclosed in US 5, 401, 962 is commercialised under the brand name "The Ferran Micropole" and is available as a high-pressure residual gas analyser. It consists of a square parallel array of nine quadrupole  
10 analysers constructed using sixteen cylindrical metal rods 1 mm in diameter and 20 mm long, mounted in miniature glass-to-metal seals. The ion source is a conventional hot-cathode device. The quadrupoles are driven in parallel by a RF generator, and the ion detector consists of an array of  
15 nine Faraday collectors connected together.

The array-type quadrupole mass spectrometer described in US 5, 719, 393 was developed by the Jet Propulsion Laboratory' (JPL) and has electrodes that are welded to metallised  
20 ceramic jigs. The ioniser is a miniature Nier type design with an iridium-tungsten filament. The detector can be a Faraday cup or a channel-type multiplier.

Quadrupole lens arrays smaller than the devices described  
25 above have been fabricated by exposing a photoresist to synchrotron radiation and then filling the resulting mould with nickel by electroplating, in a collaboration between JPL and Brookhaven National Laboratory and described in US 6,188,067. The lens assembly is a planar element, which is  
30 configured into a stacked structure in the complete mass spectrometer. However, there is no evidence of successful operation of the device.

A different micro-engineered quadrupole lens has been  
35 developed jointly by Imperial College and Liverpool

University, and is described in US 6, 025, 591. The device 100, as shown in Figure 1, consists of four cylindrical electrodes 115 mounted in pairs on two oxidised, silicon substrates 105, that are held apart by two cylindrical  
5 spacers 120. V-shaped grooves 110 formed by anisotropic wet chemical etching are used to locate the electrodes and the  

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spacers. The electrodes are metal-coated glass rods that are soldered to metal films 125 deposited in the grooves.

10 The mounting method is similar to that used to hold single-mode optical fibres in precision ribbon fibre connectors. In each case, positioning accuracy is achieved by the use of photolithography followed by etching along crystal  
15 planes to create kinematic mounts for cylindrical components. However, in the quadrupole lens, the two halves of the structure are also self-aligning. The degree of miniaturisation is only moderate, and operation has been demonstrated using devices with electrodes of 0.5 mm  
20 diameter and 30 mm length. Wirebond connectors 135 are used to provide for electrical contact to the components of the device.

Although mass filtering has been demonstrated, the method of fabrication has some disadvantages. The electrode rods  
25 require lengthy cutting, polishing and metallisation. Because the electrodes must be metal-coated everywhere, metallisation involves multiple cycles of vacuum deposition. The bonding process used to attach the  
30 electrode rods is a time consuming manual operation, requiring axial alignment. Additional fixtures are needed to hold the assembly together, and there is no axial alignment of the two substrates, which may slide over each other.

The method of fabrication also results in some important performance limitations. The oxide layer is electrically leaky, so that the drive voltage (and thus the mass range) is limited. As a result, current device performance is insufficient for applications requiring measurement of large masses (e.g. drugs or explosives detection).

There is also significant capacitance coupling to the resistive substrate, which rises as the RF frequency is increased. The device therefore forms a poor RF load, and the mass selectivity is limited. Resistance heating in the substrate also tends to melt the solder, causing the rods tend to detach from the V-grooves.

In addition, the construction forms only a mass filter, and an ion source and detector must also be added to form a complete mass spectrometer.

There is therefore a need to provide an improved mass spectrometer device which can be easily fabricated. There is a further need to provide an array-type device, which could be used to increase the currently low instrument sensitivity.

#### Object of the Invention

It is an object of the present invention to provide an improved mass spectrometer.

#### Summary of the Invention

Accordingly the present invention provides an integrated mass spectrometer device formed from two multilayer wafers, each wafer having an inner layer, an outer layer and having an insulating layer provided therebetween. The device is



provided with a plurality of electrode rods and a plurality of electrodes, the electrodes and electrode rods being formed on distinct layers of the wafers.

5 The spectrometer is desirably a quadropole mass spectrometer and the invention additionally provides a ~~method of constructing such a micro-engineered quadropole mass spectrometer, which overcomes many of the difficulties associated with the above prior art. Such a quadropole~~  
10 device requires at least four electrode rods, typically cylindrical with each rod having its diameter and centre-to-centre separation correctly chosen for quadropole operation.

15 The horizontal separation of the cylindrical electrodes within each wafer is desirably defined by lithography and deep reactive ion etching.

The vertical separation of the cylindrical electrodes is  
20 typically defined by the combined thickness of the two bonded wafers.

Each of the multilayer wafers desirably has three layers which are combined to form a five layer structure.

25 The electrode rods preferably are mountable in the outer layers of each wafer. Desirably the rods are cylindrical electrode rods and are made from metal, thus simplifying electrode preparation.

30 The outer layers of each wafer are suitably dimensioned to receive the electrode rods therein, the electrode rods being retained in contact with the outer layer by the provision of at least one resilient member formed in the  
35 outer layer. Such retention is desirably provided by

mounting the electrode rods in etched slots within the wafers and retaining them therein using silicon springs, thus simplifying assembly, avoiding the need for bonding material, and reducing the likelihood of detachment. The slots and springs are typically etched in bonded silicon-on-insulator substrates, using deep reactive ion etching. The precision of the assembly is determined by a combination of lithography and deep etching, and by the mechanical definition of the bonded silicon layers.

10

Each of the first and second wafers are typically patterned with an outer pattern on a first side, and an inner pattern on a second side. The use of both sides of each wafer is thereby enabled.

15

The patterns provided on the second side typically provide for ion source and ion collection components of the spectrometer.

20

The insulating layer is desirably provided in regions where the patterns overlap.

25

The first and second wafers are typically bonded to form a monolithic block. The bonding is desirably effected in such a manner that the electrode rods are located on an outer portion of the block and the electrodes in an inner portion of the block.

30

At least some of the plurality of electrodes are desirably adapted to form ion entrance optics. These ion entrance optics are typically formed by an einzel lens.

A cold cathode field emission electron source may be provided in front of the ion entrance optics.

35

In another embodiment a pair of RF electrodes are placed in front of the ion entrance optics in order to create a plasma.

- 5 In a further embodiment the ion entrance optics are formed from an etched fluid channel combined with a set of  
~~electrodes that together define an electrospray source.~~
- 

10 Two or more devices may be combined to form an array which may be formed either as a plurality of devices formed in parallel or in series. When in series the array forms a tandem mass spectrometer, which may include a pair of electrodes provided between each pair of the devices in the series so as to form a plasma

15

The invention additionally provides a method of forming a mass spectrometer comprising the steps of:  
etching an inner and outer pattern on a wafer, the inner and outer patterns defining components for the spectrometer,  
20 bonding the wafer to a second wafer so as to form a multilayer stack device,  
inserting at least one electrode rod into the device.

It will be appreciated that the quadrupole geometry is  
25 achieved using two substrates, which are aligned and bonded into a single block using a bonding tool. The formation of a monolithic block increases the rigidity and reliability of the device. No additional components are required to align the structure or hold it together. The mounting of  
30 electrodes on the outside of the two substrates ensures that it is easier to access and position the electrodes. Electrical isolation is desirably provided by thick layer of high quality silicon dioxide, thus minimising leakage and maximising the voltage that can be applied. The  
35 majority of the silicon around the rods is typically

removed, thus minimising capacitance coupling and maximising the usable frequency.

Ion coupling optics and other features such as fluidic  
5 channels may be incorporated in the structure. Because the electrodes are on the outside, it is simple to construct an array device. Cascaded devices such as tandem mass spectrometers may be constructed in a similar way.

10 These and other features of the present invention will be better understood with reference to the drawings and description thereof which follow.

#### Brief Description of the Drawings

15

Figure 1 shows a prior art micro-engineered quadrupole electrostatic lens,

Figure 2 is a plan view showing a) the outer and b) the inner etched patterns in a monolithic, micro-engineered  
20 mass spectrometer according to the present invention,  
Figure 3 is a plan view showing a) the registration of the outer and inner pattern, and b) the location of the electrode rods by the outer pattern in a device according to the present invention,

25 Figure 4 is a cross-sectional view, showing a) wafer bonding and b) electrode rod insertion of the device of Figure 3,

Figure 5 is a simplified flow chart showing the fabrication steps involved in the construction of a monolithic,  
30 microengineered mass spectrometer according to the present invention,

Figure 6 is a schematic illustrating electrical connections to a monolithic, micro-engineered mass spectrometer according to the present invention,

Figure 7 is a schematic showing the location of a) a cold cathode field emission electron source, b) an RF plasma source and c) an electrospray source at the input to a monolithic, micro-engineered mass spectrometer according to preferred embodiments of the present invention, and Figure 8 is a schematic showing the location of a collision chamber between cascaded quadrupole lenses, as required in tandem mass spectrometry.

#### 10 Detailed Description of the Drawings

Figure 1 has been described with reference to the prior art.

15 The present invention will now be described with reference to Figures 2 - 6, which show an example of a new method of construction, based on deep-etched features formed in bonded silicon-on-insulator (BSOI) material, according to a preferred embodiment of the invention. BSOI consists of an  
20 oxidised silicon wafer, to which a second silicon wafer has been bonded. The second wafer may be polished back to the desired thickness, to leave a silicon-oxide-silicon multi-layer. BSOI wafers typically find application in high-voltage microelectronics. However, the different layers in  
25 the wafer may also be processed using semiconductor microfabrication techniques to yield a three-dimensional structure.

In accordance with the present invention two BSOI wafers  
30 are required, each with a double-side polish. Figure 2 shows how each wafer may be patterned with an outer pattern on the first side 200 (Figure 2a) (the original substrate wafer side), and an inner pattern on the second side 205 (Figure 2b) (the bonded wafer side). The features are  
35 desirably made by deep reactive ion etching (DRIE), a

process used to form near vertical trenches with very high precision.

The pattern is transferred into the silicon from a shallower surface mask layer, which is resistant to the reactive species commonly employed in deep reactive ion etching. Suitable mask materials are thick layers of hard-baked photoresist and silicon dioxide. The first steps of processing therefore involve deposition and patterning of the mask layers. Photoresist may be spin-coated and patterned by photolithography. Silicon dioxide may be formed by thermal oxidation or coated by chemical vapour deposition. It can be patterned by reactive ion etching, using a thinner layer of photoresist as a mask.

There is considerable flexibility in the patterns that may be used. The following description, with reference to Figure 2 to 6, corresponds to an exemplary embodiment that illustrates advantages of the constructional approach provided by the present invention and the differences from the prior art previously described, and it will be appreciated by those skilled in the art that modifications to the specific pattern described may be effected without departing from the scope of the invention. Further aspects are illustrated in Figures 7 and 8.

Figure 2a shows a plan view of the outer pattern 200. This pattern is adapted to provide for the retention of electrodes and in this illustrated embodiment consists of a set of locating features 210, 215 for two cylindrical electrode rods (not shown), and two flexible members which are shown as springs 220, 225 to retain the rods in place. The rod diameters are comparable to the thickness of the wafer.

Figure 2b shows a plan view of the inner pattern 205. At the left-hand end, this pattern consists of a set of three electrodes 230, 235, 240 that can act as an einzel lens, a common electrostatic optical component that is used to focus charged particles into an electron or ion optical system. At the right-hand end, this pattern consists of a similar (but not identical) set of two electrodes 245, 250 that can act as a Faraday cage and an ion collector at the exit of the system. In effect, the first and second sets of electrodes form the ion source and ion counter - the entrance and exit optic pupil components of the spectrometer device.

The patterns may be etched through the entire thickness of the bonded layer. Alternatively, more complicated processing involving two mask layers may be used to limit the depth of the pattern in some areas. For example, a small thickness of the silicon may be left linking the upper and lower electrodes in the einzel lens and the Faraday cage, as shown by the dashed lines in Figure 2b.

Figure 3a shows the relationship of the outer and inner patterns. In some areas, additional features are added to the outer pattern to ensure mechanical continuity between the two layers, so that the overall structure is rigid. In other areas, the outer layer pattern is cut away, so that all the electrodes may be accessed from the outer side of the structure. The two patterns may be registered together with high accuracy using a double-side mask aligner.

Figure 3b shows the eventual location of cylindrical electrode rods 300 within the outer layer pattern. The locating springs 220, 225 hold the two rods so that they are symmetrically displaced on either side of an optical axis defined by the entrance and exit optic pupils formed

by the patterns on the inner layer. The springs also make electrical contact to the electrode rods.

As shown in the sectional view of Figure 4a, an oxide  
5 interlayer or insulating layer 400 is provided between the  
inner and outer layers of each wafer. After deep reactive  
ion etching, the oxide interlayer is partially removed by  
wet chemical etching, to leave oxide remaining only in the  
10 regions where the patterns in the inner and outer layers  
overlap. It will be appreciated that certain applications  
may require the addition of additional oxide insulation to  
be provided over the structure by thermal oxidation, or by  
a coating process such as chemical vapour deposition.  
Further processing is then used to provide metal contacts  
15 to each silicon electrode in the entrance and exit optical  
system, and to the silicon springs that retain the  
cylindrical electrodes. Because the contacts may all be  
accessed from the outer layer of the structure, this metal  
may be added by single-sided vacuum deposition.

20 Once each of the two wafers have been patterned they may be  
aligned together and bonded to leave a silicon-oxide-  
silicon-oxide-silicon multilayer stack 410, as shown in the  
cross-sectional view of Figure 4a. It will be appreciated  
25 that each wafer comprises three layers; the outer and inner  
layers and a isolation layer provided therebetween. In the  
bonding process each of the inner layers are integrally  
bonded to form a bond interface 420, such that in the  
complete stack only five distinct layers are present. The  
30 alignment and bonding may be carried out using a variety of  
techniques such as a bonding tool equipped with a  
microscope and mechanisms for compression and heating. The  
resulting composite wafer is then diced to separate the  
individual dies. At this stage, each device is a single  
35 rigid, monolithic block. Each device is then attached to a



submount, and wirebond connections are made to the contact metallisation.

5 Metallic electrodes 300, desirably cylindrical, are then inserted into the block 410 from the outside, as shown in the cross-sectional view of Figure 4b. In the example of a

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quadrupole spectrometer, four electrodes are utilised and each of the four electrodes have their diameters and centre-to-centre separations chosen for quadrupole

10 operation. The horizontal position of each electrode is defined by the locating features and springs etched into the outer layer pattern. The vertical separation of the electrodes is defined by the thickness of the two inner bonded silicon layers, which may be accurately specified in

15 commercially available BSOI material.

The fabrication process above is summarised in Figure 5. This figure shows the steps of (1) depositing a mask layer on the first and second sides of a wafer; (2) patterning the

20 mask layer on the first and second sides; (3) deep reactive ion etching of the first and second sides of the wafer; (4) removal of residual portions of the mask layer; (5) wet etching of the oxide interlayer; (6) metallisation of the first side of the wafer; (7) bonding of two wafers into a

25 two-wafer stack; (8) dicing of the resulting composite wafer; (9) mounting and wirebonding of individual dies, and (10) insertion of cylindrical electrode rods.

Electrical connections to the device are made as shown in

30 Figure 6. DC voltages  $V_1$ ,  $V_2$  and  $V_3$  are applied to the einzel lens electrodes and  $V_4$  to the Faraday cage. Voltages  $V_{RF1}$  and  $V_{RF2}$  containing both a DC and an AC component are applied to the cylindrical electrodes. The DC and AC components have the ratios commonly used in quadrupole mass

35 spectrometers to provide mass filtering. The ion current  $I$

is collected from the electrode to the right of the Faraday cage and passed to a transimpedance amplifier ( not shown).

The electrodes provided in the description above are  
5 suitable for coupling an ion flux into the quadrupole assembly, performing a mass filtering operation, and detecting the resulting filtered stream of ions. Further components are required to create the ion flux. Figures 7a and 7b show modifications to the previous structure so as  
10 to optimise the performance for gaseous analytes. Figure 7c shows a modification appropriate for liquid analytes,

For a gaseous analyte, ionisation may be carried out by electron bombardment. A suitable electron stream may be  
15 provided by a cold-cathode field emission electron source, fabricated as a planar array of Spindt emitters 700. The source may be located (for example, by hybrid integration) on an etched silicon terrace, immediately in front of the ion input coupling optics as shown in Figure 7a. The source  
20 is arranged to emit electrons in a direction perpendicular to the main axis of the mass spectrometer, so that the electron and ion streams may be efficiently separated.

Alternatively, ionisation may be carried out within a gas  
25 plasma, which itself may be created by an RF electric field 705, as shown in Figure 7b. The field may be established between a pair of electrodes located on etched silicon terraces, located immediately in front of the ion input coupling optics.. Again, the RF field is arranged to  
30 accelerate electrons in a direction perpendicular to the main axis of the mass spectrometer, so that the electron and ion streams may be efficiently separated.

For a liquid analyte (for example, as provided by a liquid  
35 chromatography column), ionisation may be carried out

within an electrospray source, A suitable source may be constructed by using an etched capillary channel 710 located immediately in front of the ion input coupling optics as shown in Figure 7c. Liquid may be extracted from  
5 such a channel as a stream of charged droplets by a nearby electrode held at a sufficiently large DC potential.

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It will be appreciated by those skilled in the art that all of the above may be implemented using the process described  
10 in Figure 5, or by modifications thereto that either involve simple alterations to the layout of the etched structures, or that require additional steps of metal and oxide deposition, patterning and etching.

15 It will be appreciated that although it has been described with reference to the formation of distinct devices that the fabrication approach described above (namely, the use of patterning, deposition and etching to create a number of similar structures on a semiconductor wafer) may clearly be  
20 extended to create parallel arrays of devices in close proximity, which may act as an array-type mass spectrometer. The quadrupole lenses may be driven in parallel, and the ion currents summed, to obtain an increase in instrument sensitivity. Alternatively, the  
25 quadrupole lenses may be driven separately, and the ion currents measured separately, to obtain a separate measure of a number of different ion species.

The fabrication approach described above may also be  
30 extended to create serial arrays of devices in close proximity, which may provide advanced functionality. For example, Figure 8 shows two quadrupole lenses 800, 805, which are connected in series to act as a tandem mass spectrometer. The first quadrupole 800 may be set to pass  
35 only those ions that have masses in a particular range,

thus acting as a prefilter. The selected ions may be fragmented in a collision chamber 810 , and passed to the second quadrupole 805 for further analysis.

5 The collision chamber is desirably a small volume within which a plasma may be created by excitation of an inert gas (for example, argon) using a pair of RF electrodes 815. The construction of a collision chamber using the methods described above merely involves additional steps of metal  
10 and oxide deposition, patterning and etching. These additional steps will be apparant to those skilled in the art.

The present invention provides a mass spectrometer that is advantageous over prior art devices. Utilising a device  
15 according to the present invention it is possible to provide for more complex mass analysis than was hereintobefore possible by cascading quadrupole filters. The device of the present invention is also advantageous in that it enables the connection of a quadrupole filter to  
20 fluidic devices containing etched channels, such as in a gas or liquid chromatography system (for example, as in a gas chromatograph mass spectrometer or GC-MS system), so as to extend the range of applications of such devices.

25 The words "comprises/comprising" and the words "having/including" when used herein with reference to the present invention are used to specify the presence of stated features; integers, steps or components but does not preclude the presence or addition of one or more other  
30 features, integers, steps, components or groups thereof. Similarly the words "upper", "lower", "right hand side", "left hand side" as used herein are for convenience of explanation and are not intended to limit the application of the device or technique of the present invention to any  
35 one specific configuration.

Claims

1. An integrated mass spectrometer device formed from two  
5 multilayer wafers, each wafer having an inner layer, an  
outer layer and having an insulating layer provided  
therebetween, the device having a plurality of electrode  
rods and a plurality of electrodes, the electrodes and  
electrode rods being formed on distinct layers of the  
10 wafers.
2. The device as claimed in claim 1 wherein each of the  
multilayer wafers has three layers which are combined to  
form a five layer structure.
- 15 3. The device as claimed in claim 1 or 2 wherein the  
electrode rods are mountable in the outer layers of each  
wafer.
- 20 4. The device as claimed in claim 3 wherein the outer layers  
of each wafer are dimensioned to receive the electrode  
rods therein, the electrode rods being retained in  
contact with the outer layer by the provision of at least  
one resilient member formed in the outer layer.
- 25 5. The device as claimed in claim 4 wherein the at least one  
resilient member is provided by a spring formed in the  
wafer.
- 30 6. The device as claimed in claim 4 wherein the electrode  
rods are located by etched features in the outer layer of  
the wafer, the features being dimensioned so as to  
suitably receive a rod, and wherein the resilient members  
is formed by also etching the outer layer.

7.The device as claimed in any preceding claim wherein each of the first and second wafers are patterned with an outer pattern on a first side, and an inner pattern on a second side.

5

8.The device as claimed in claim 7 wherein the patterns provided on the second side provides for ion source and ion collection components of the spectrometer.

10

9.The device as claimed in claim 7 or 8 wherein the insulating layer is provided in regions where the patterns overlap.

15

10.The device as claimed in any preceding claim wherein the first and second wafers are bonded to form a monolithic block.

20

11.The device as claimed in claim 10 wherein the bonding of the first and second wafers is effected such that the electrode rods are located on an outer portion of the block and the electrodes in an inner portion of the block.

25

12.The device as claimed in any preceding claim including four cylindrical electrode rods, each rod having its diameter and centre-to-centre separation correctly chosen for quadrupole operation.

30

13.The device as claimed in claim 12 wherein the horizontal separation of the cylindrical electrodes within each wafer is defined by lithography and deep reactive ion etching.

35

14.The device as claimed in claim 12 or 13 wherein the vertical separation of the cylindrical electrodes is

defined by the combined thickness of the two bonded wafers.

15. The device as claimed in any preceding claim wherein at  
5 least some of the plurality of electrodes are adapted to form ion entrance optics.

---

16. The device as claimed in claim 15 wherein the ion  
entrance optics are formed by an einzel lens.

10 17. The device as claimed in claim 15 further including a cold cathode field emission electron source provided in front of the ion entrance optics.

15 18. The device as claimed in claim 15 wherein a pair of RF electrodes are placed in front of the ion entrance optics in order to create a plasma.

19. The device as claimed in claim 15 wherein the ion  
20 entrance optics are formed from an etched fluid channel combined with a set of electrodes that together define an electrospray source.

20. The device as claimed in any preceding claim wherein  
25 each of the wafers are bonded silicon on insulator wafers.

21. A mass spectrometer array comprising a plurality of  
devices as claimed in any preceding claim.

30 22. A mass spectrometer system comprising two or more devices as claimed in any one of claims 1 to 20, the two or more devices being provided in series so as to form a tandem mass spectrometer.

23. A mass spectrometer system as claimed in claim 22,  
wherein each of the devices forming the series of devices  
is a quadropole device and wherein a pair of RF  
electrodes are placed between the cascaded quadropole  
5 devices in order to create a plasma.

24. A method of forming a mass spectrometer comprising the  
steps of:

- 10 a) etching an inner and outer patter on a wafer, the  
inner and outer patterns defining components for  
the spectrometer,
- b) bonding the wafer to a second wafer so as to form  
a multilayer stack device,
- 15 c) inserting at least one electrode rod into the  
device.

25. A device substantially as hereinbefore described with  
reference to and/or as illustrated in the any one of  
Figures 2 to 8 of the accompanying drawings.

20 26. A method of forming a device substantially as  
hereinbefore described with reference to and/or as  
illustrated in the any one of Figures 2 to 8 of the  
accompanying drawings.



AbstractMonolithic Micro-engineered Mass Spectrometer

A method of constructing a micro-engineered mass  
5 spectrometer from bonded silicon-on-insulator (BSOI) wafers  
is described with reference to a quadrupole spectrometer.

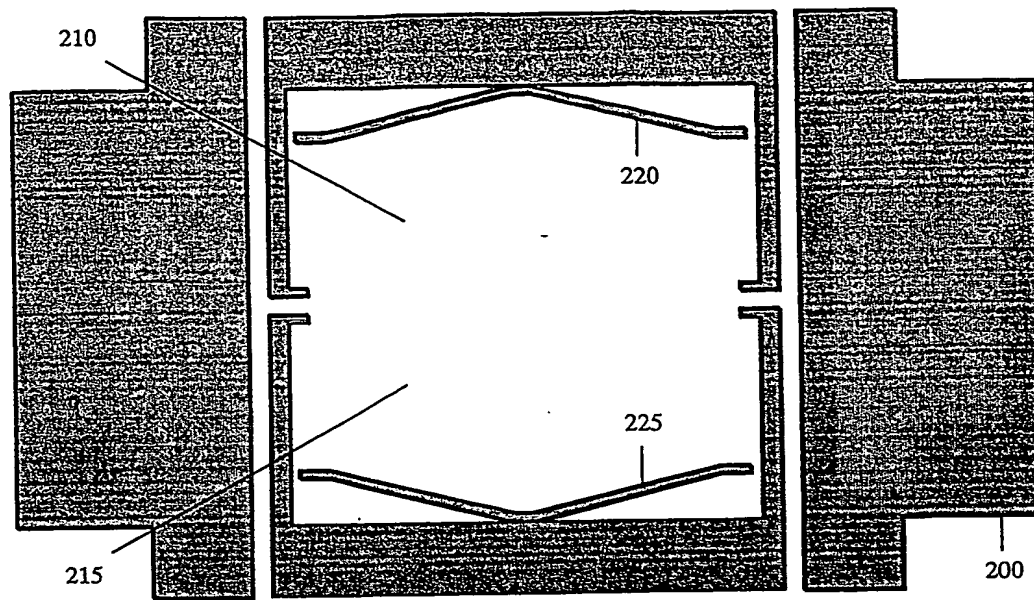
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The quadrupole geometry is achieved using two BSOI wafers  
200, which are bonded together to form a monolithic block  
410. Deep etched features and springs formed in the outer  
10 silicon layers are used to locate cylindrical metallic  
electrode rods 300. The precision of the assembly is  
determined by a combination of lithography and deep  
etching, and by the mechanical definition of the bonded  
silicon layers. Deep etched features formed in the inner  
15 silicon layers are used to define ion entrance and ion  
collection optics. Other features such as fluidic channels  
may be incorporated.

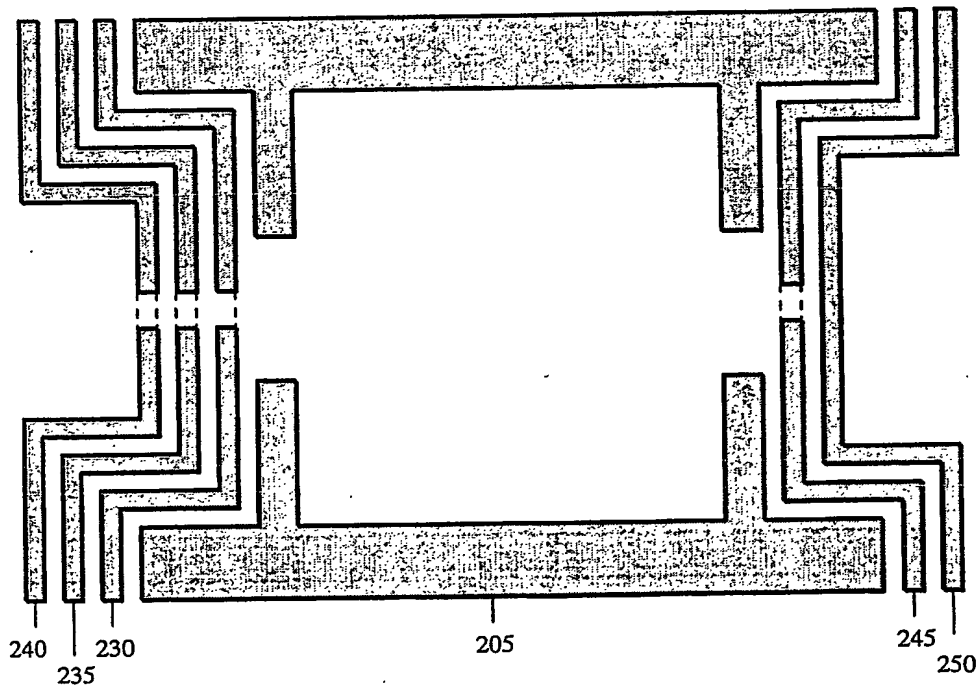
[Figure 4b]

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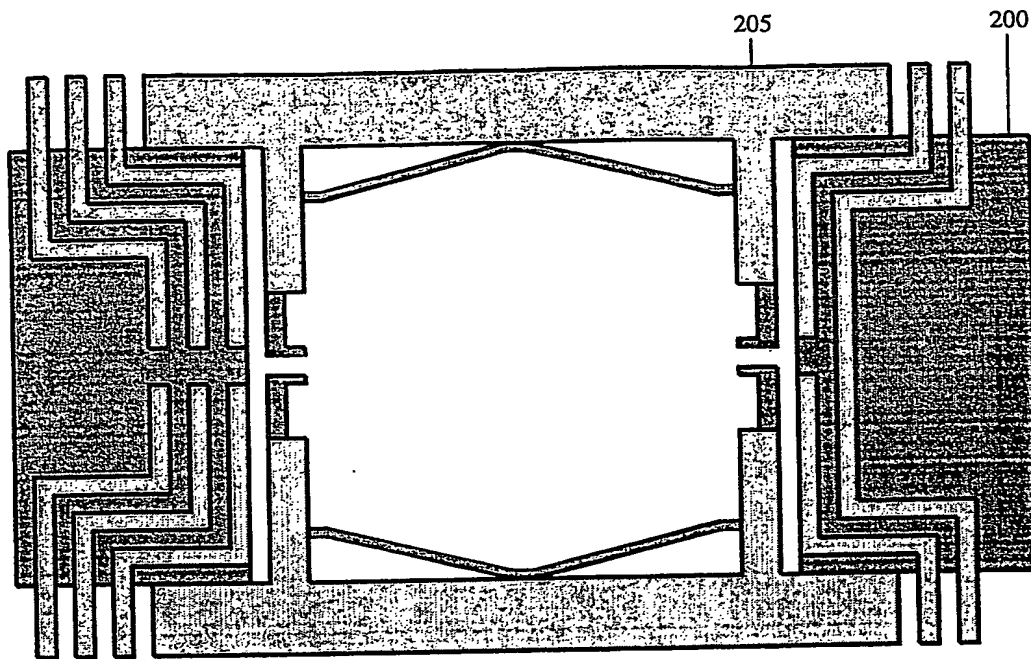


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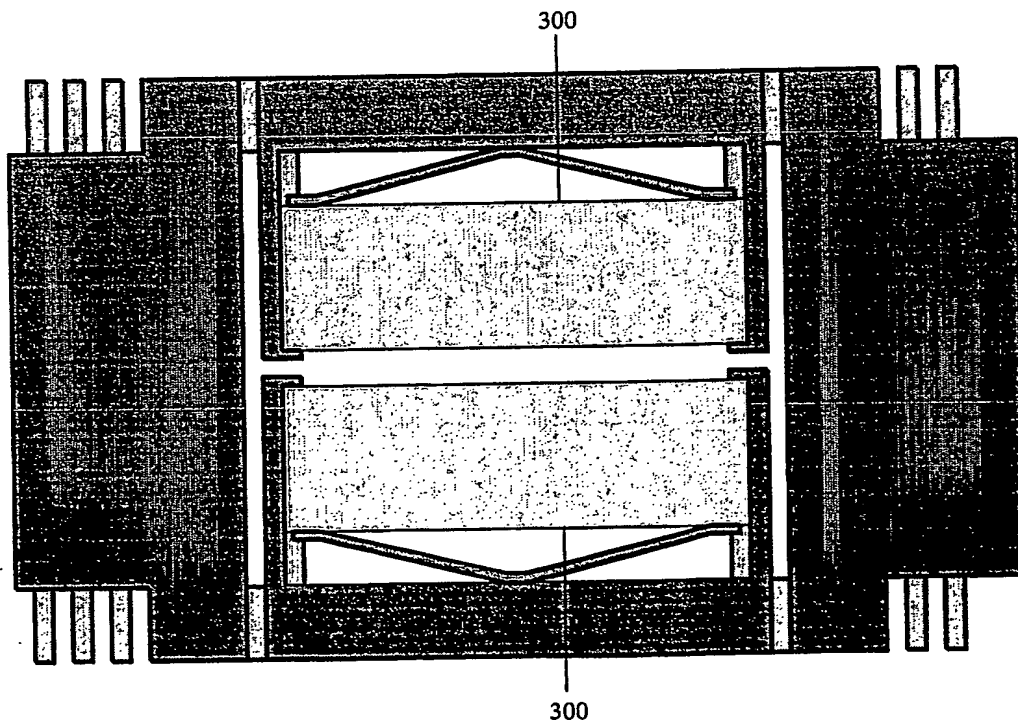


b)

Figure 2.

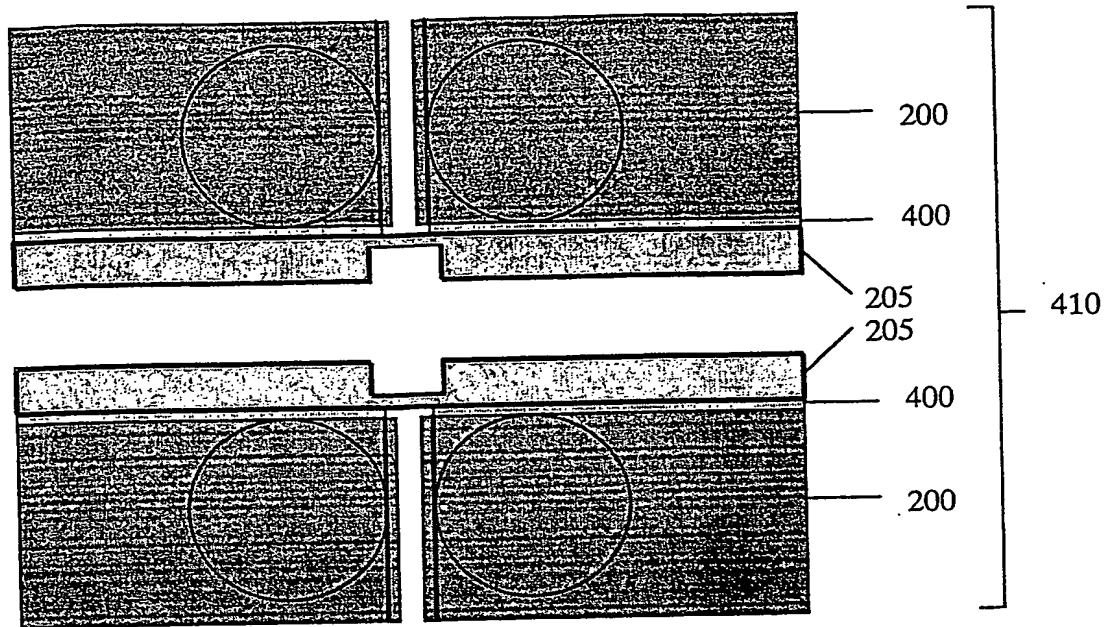


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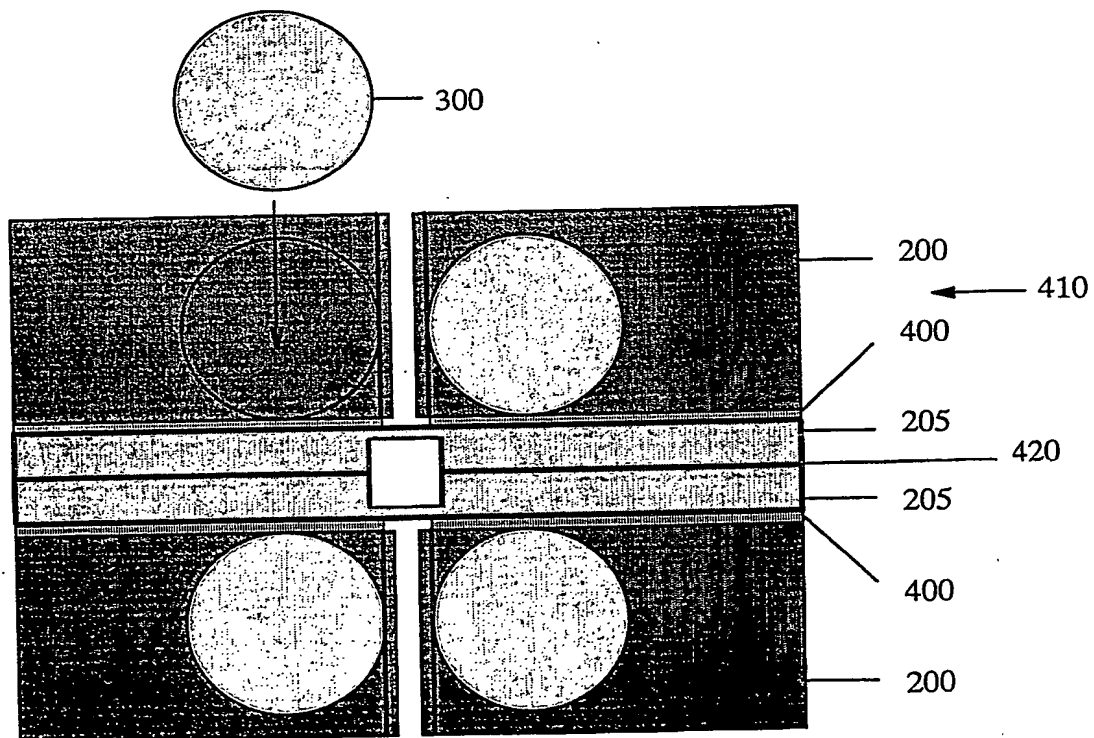


b)

Figure 3.



a)



b)

Figure 4.

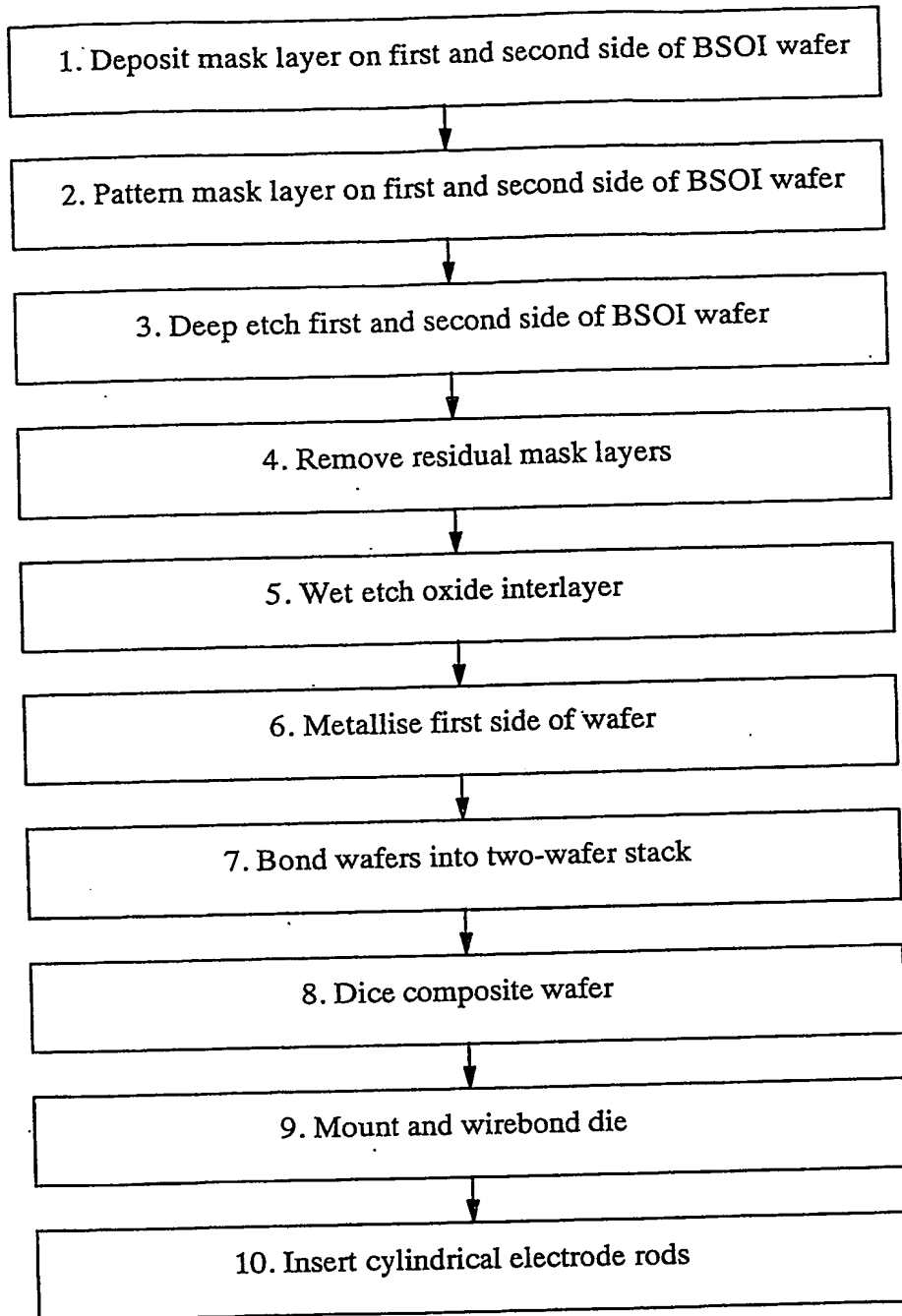


Figure 5.

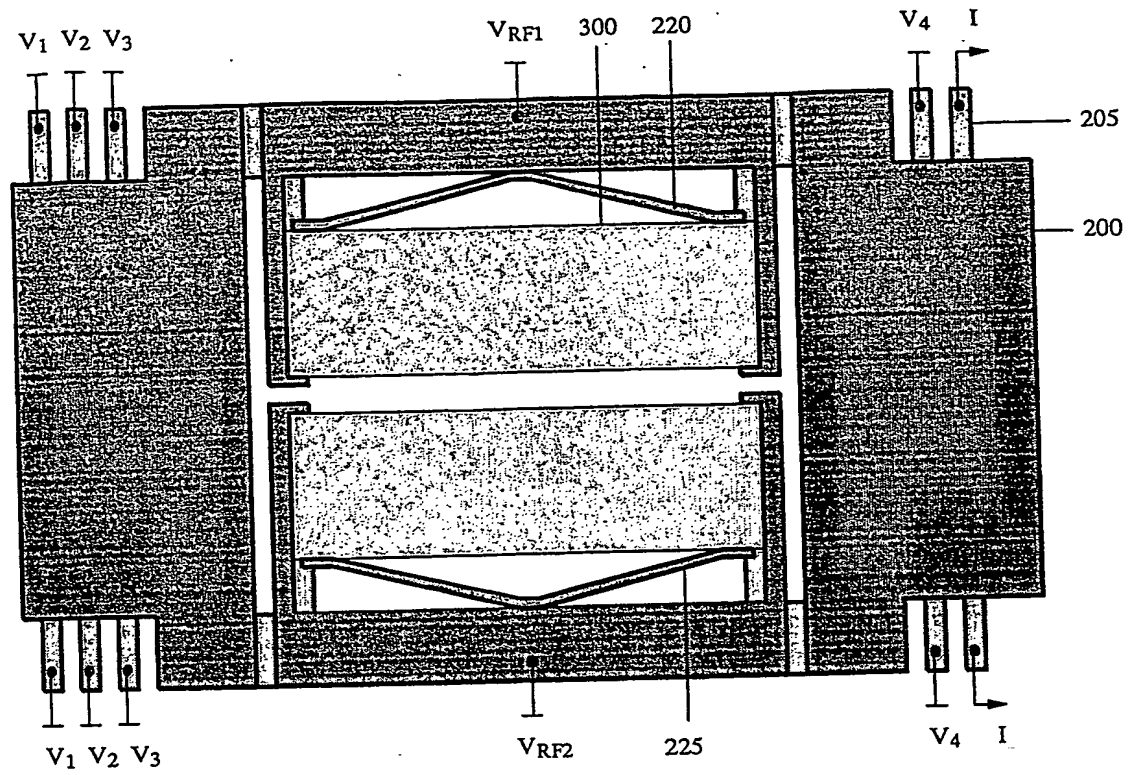
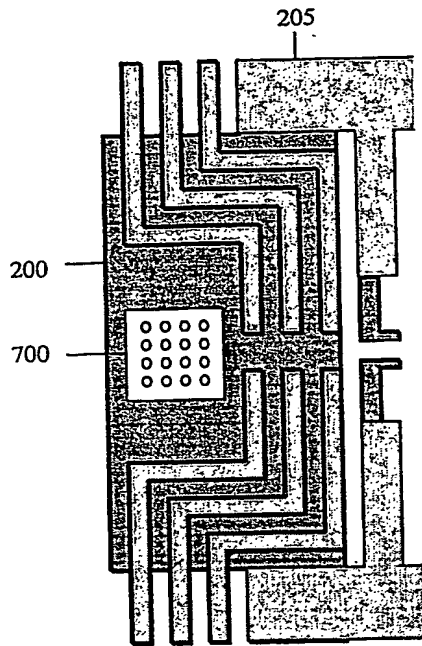
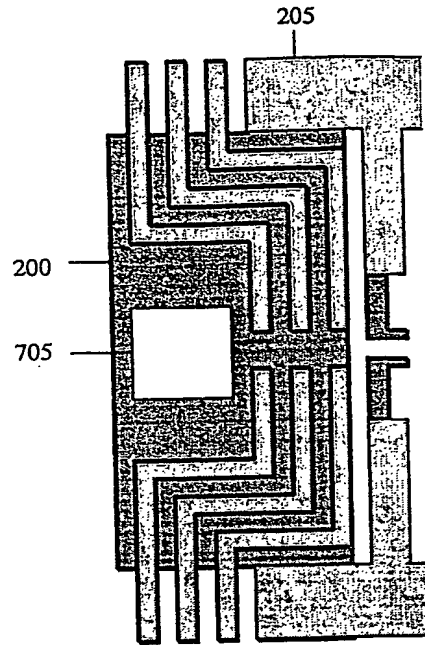


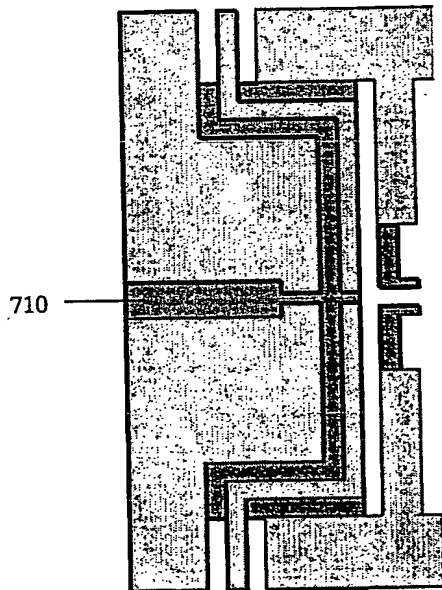
Figure 6.



a)



b)



c)

Figure 7.



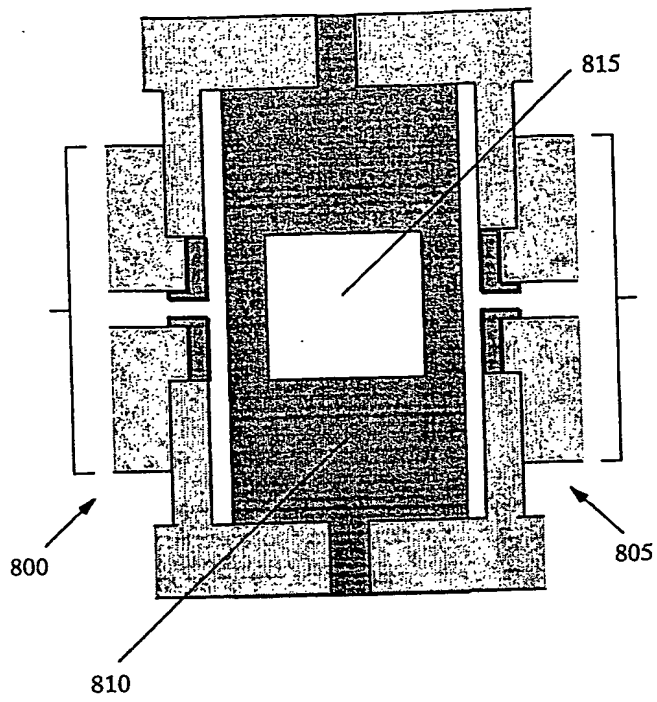


Figure 8.

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